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FECONDITY OF THE PACIFIC HAKE, *MERLUCCIIUS PRODUCTUS*, SPAWNING IN CANADIAN WATERS

Previous studies on the fecundity of Pacific hake, *Merluccius productus*, have been concentrated on the coastal stock in Baja California (MacGregor 1966, 1971; Ermakov et al. 1974), although large-scale spawning events have been recorded as far north as lat. 38°N, near San Francisco, CA (Stepanenko 1980). The present work was undertaken in conjunction with ichthyoplankton surveys, aimed at estimating the released egg production and spawning biomass of the Pacific hake stock resident in the Strait of Georgia, a semi-closed marine basin in British Columbia (Thomson 1981). The spawning season extends from February through June, peaks in early April, and is 90% complete by mid-May (Mason et al. 1984).

In comparison with the coastal stock of some 1-2 million metric tons (t) (Bailey et al. 1982), this inshore stock, of about 140,000 t, is subject to modest annual exploitation (1-500 t) and resides in a semi-estuarine environment on the known northernmost edge of the reproductive range. The coastal stock undertakes a northward feeding migration after the spring spawning and reaches the southwest coast of Vancouver Island by late summer (Bailey et al. 1982). There is no evidence of intermingling between these two stocks, based on their distributional patterns. The inshore stocks in the Strait of Georgia and Puget Sound may undergo some exchange, possibly due to surface transport of larvae produced in the central Strait of Georgia (Mason et al. 1984). The Puget Sound and coastal stocks have been identified as genetically distinct by Utter and Hodgins (1971), but the two inshore stocks in Puget Sound and

the Strait of Georgia have not been similarly compared.

Histological analysis has indicated that only one mode of oocytes develops in Georgia Strait hake. However, like the Baja, California form and hake species elsewhere, some Strait of Georgia hake show evidence of ovarian resorption following spawning (Foucher and Beamish 1980). The quantitative significance of resorption relative to individual and stock fecundities, or to their potential physiological and environmental correlates have not yet been examined. This report considers the "apparent fecundity" as an annual expression of reproductive potential applicable to the stock in the Strait of Georgia, determines that fecundity, and concludes that ovarian resorption is of minor consequence in the stock.

Materials and Methods

The ovaries of 97 Pacific hake females 39-82 cm FL were collected during late February and early March of 1980 and 1981, 71 of which were collected in 1981 (McFarlane et al. 1983). Unspawned females were selected in maturity stages R^2 and R (Foucher and Beamish 1977) when the ovary is yellow and opaque, has prominent blood vessels, and fills one-third to one-half of the coelomic cavity. No ovaries contained translucent oocytes which signify imminent spawning. Fresh ovaries were preserved in 10% formaldehyde solution. In the laboratory, the preserved ovaries were transferred to modified (Simpson 1951) Gilson's fluid for several months to allow breakdown of connective tissue.

Ovaries were then washed thoroughly in cold water over a series of stainless steel screens of 40 μ m and larger aperture, and gently broken up by hand when necessary to separate the hardened eggs from the ovarian tissue. The mesh size of the finest screen was determined by the difficulty encountered in separating oocytes <40 μ m diameter from ovarian tissue. The cleaned eggs were then stored in 5% formaldehyde solution in preparation for analysis.

Eggs from a single ovary were transferred to a 20 L glass reservoir filled to either 10 or 15 L. While the reservoir was being stirred vigorously with a wooden paddle in a rotating figure-eight pattern, a second worker extracted 50 1-2 mL volumetric subsamples using Stempel pipettes and transferred them to petri dishes. Under the dissecting microscope at 50 \times magnification, all eggs in five subsamples were sized and counted in 20 μ m intervals of oocyte diameter. These results were then combined to construct oocyte size-frequency histograms and

to allot proportions of the combined egg count to the various size intervals. All eggs were counted in the remaining 45 subsamples to provide with the previous 5 subsamples, 50 counts of eggs per unit volume. The total number of eggs in the ovary was calculated from the product of mean subsample count per milliliter and the reservoir volume prior to subsampling. The number of eggs in various size categories was obtained by applying the appropriate proportional value to the estimated total number of eggs in the ovary. Subsample egg counts averaged between 50 and 150 eggs, with the majority falling within 75 and 100. Size-frequency histograms were based on 250-750 sized eggs with the majority based on 375-500 sized eggs. Initial procedural evaluation indicated that 200 sized eggs was sufficient to obtain a replicable size-frequency distribution.

Eighteen ovaries from postspawned females were collected on 3 July 1981 and were similarly processed.

Prespawning females collected in 1981 were aged by the otolith break and burn method (Chilton and Beamish 1982).

Results and Discussion

Frequency Distributions of Oocyte Diameter for Prespawners

Most of the 97 ovaries of prespawners examined contained a pronounced bimodal distribution of oocyte diameters with peaks at about 100 μm and between 500 and 600 μm (Figs. 1-3). Oocytes <150 μm in diameter contained no yolk materials and are taken to constitute a reserve fund for subsequent years (Foucher and Beamish 1980). Oocytes >150 μm diameter were undergoing vitellogenesis, and a few ovaries contained nonhydrated oocytes reaching 700-750 μm diameter. Hydrated eggs were not seen in these ovaries collected in early March and hydration probably does not occur in oocytes <700 μm , although hydrated oocytes from 350 to 950 μm diameter were found by Foucher and Beamish (1980). This apparent discrepancy may reflect their underestimation of oocyte diameters in histological preparations of translucent oocytes due to the plane of sectioning.

The unimodal distribution of yolked oocytes, also reported for *M. m. hubbsi* in the Argentine Sea (Christiansen and Cousseau 1971) does not complement the findings of MacGregor (1966, 1971). He found that ovaries of prespawning coastal hake taken off Baja California contained distinct groups of "small" and "large" yolked oocytes, of which only the

latter were destined for release. Furthermore, Ermakov et al. (1974) reported 21% of the 93 female Pacific hake taken off Baja California in 1972 had unimodal, 55% bimodal, 18% trimodal, and 6% quadrimodal oocyte distributions. Similarly, their subsequent sample of 45 ovaries collected in the Oregon-Washington region in late November contained 22% unimodal, 65% bimodal, and 6% trimodal distributions, with major peaks at 200 and 600 μm diameter. Nearly half of the ovaries collected and examined by Ermakov et al. (1974) did not contain a bimodal distribution of yolked oocytes, although these authors concluded that asynchronous development of yolked oocytes indicated the probability of multiple spawnings, most likely two batches within the spawning season.

Estimates of Total Fecundity

Standard errors of mean egg counts for total fecundity estimates of total fecundity (oocytes ≥ 40 μm diameter) ranged between 0.4 and 4.4% of the means and were <3% in nearly 70% of the 97 ovaries processed. The variability of the enumeration technique compares favorably with that reported by Mason et al. (1983) in an analysis of the fecundity of the sablefish, *Anoplopoma fimbria*, and with that reported by Pitt (1963) on the fecundity of the American plaice, *Hippoglossoides platessoides*, using Wiborg's whorling vessel (Wiborg 1951).

The estimates of total fecundity (oocytes ≥ 40 μm diameter) increased with fork length according to the equation $F = 0.3081\text{FL}^{3.7605}$, [where FL = fork length in centimeters]. The correlation coefficient (r) for the regression was 0.93. An insignificant F ratio from analysis of variance of slope and intercept values allowed pooling of the 1980 and 1981 data.

The smallest and largest Pacific hake females in the sample (39 and 82 cm FL) contained estimated total oocyte complements of 202,100 and 3,009,900 oocytes ≥ 40 μm , respectively. All 97 fecundity estimates fell within the range of 165,700 and 3,108,000 oocytes ≥ 40 μm .

Estimates of Fecundity Within Size Classes of Oocytes

The estimated number of oocytes with 20 μm intervals of diameter were summed within five intervals and regressed against fork length to examine the correlation coefficients (Table 1). Coefficients declined progressively with increased oocyte diameter, reflecting increasing variability among

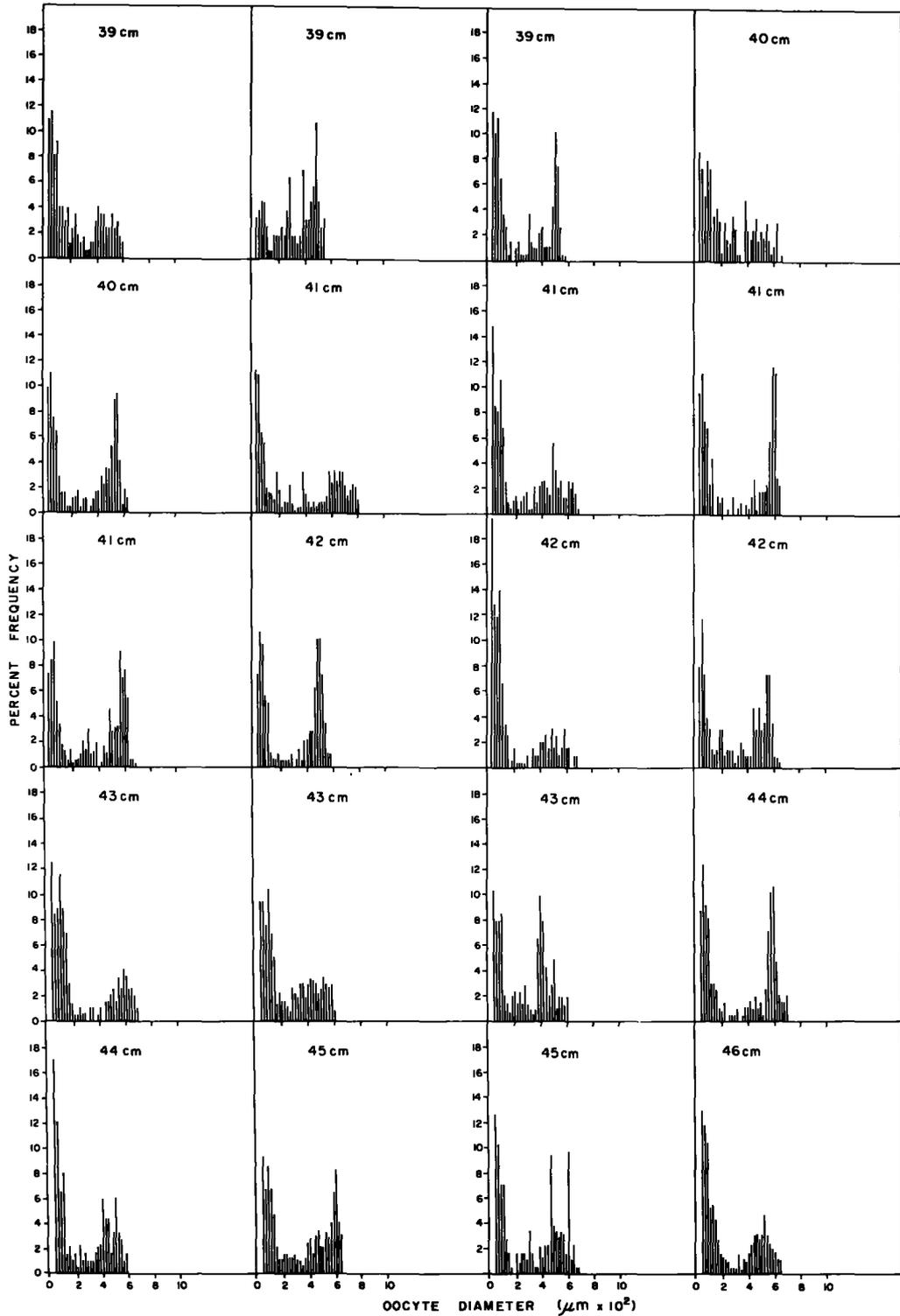


FIGURE 1.—Representative frequency distributions of oocyte diameter from ovaries of Pacific hake 39-46 cm FL.

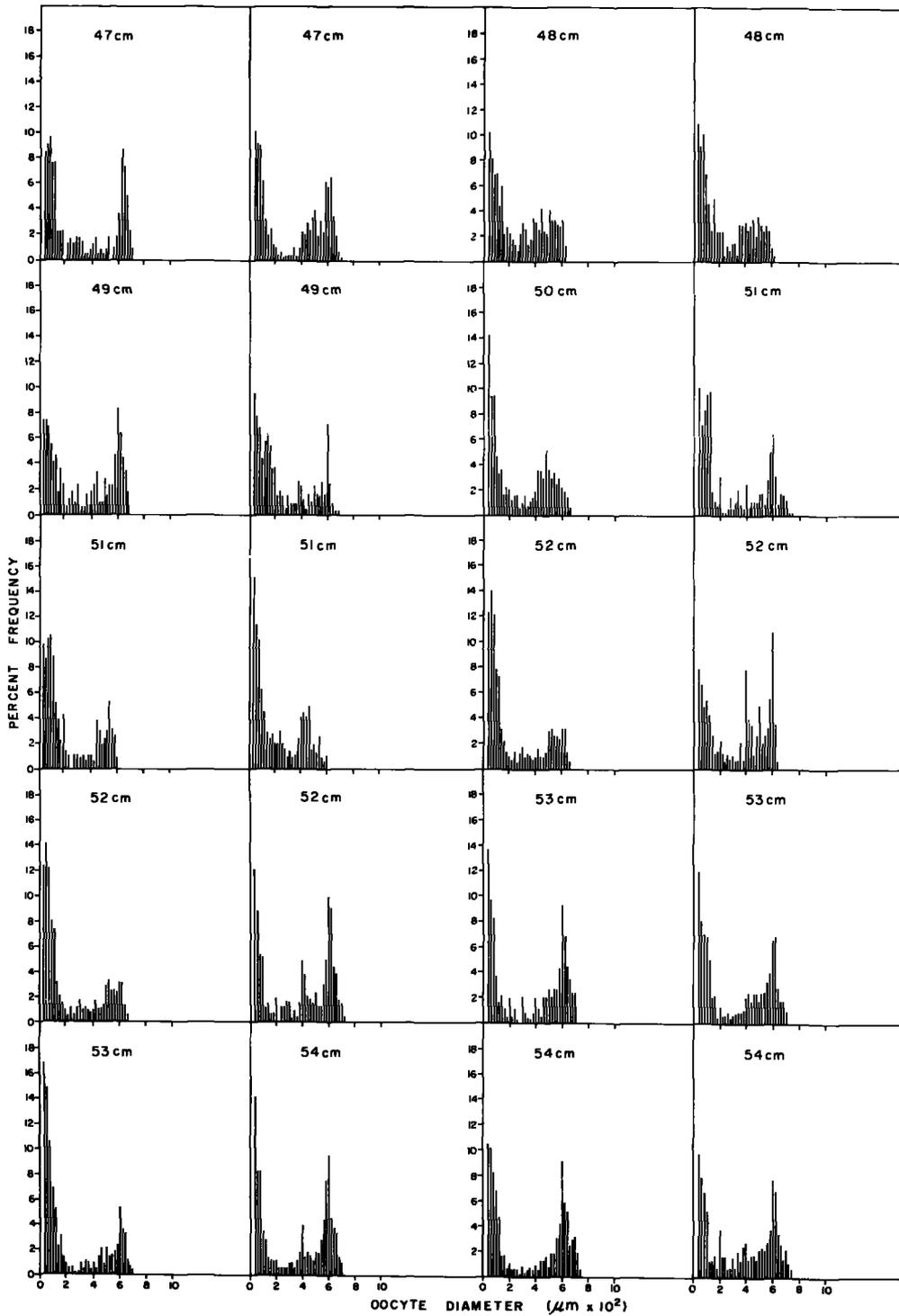


FIGURE 2.—Representative frequency distributions of oocyte diameter from ovaries of Pacific hake 47-54 cm FL.

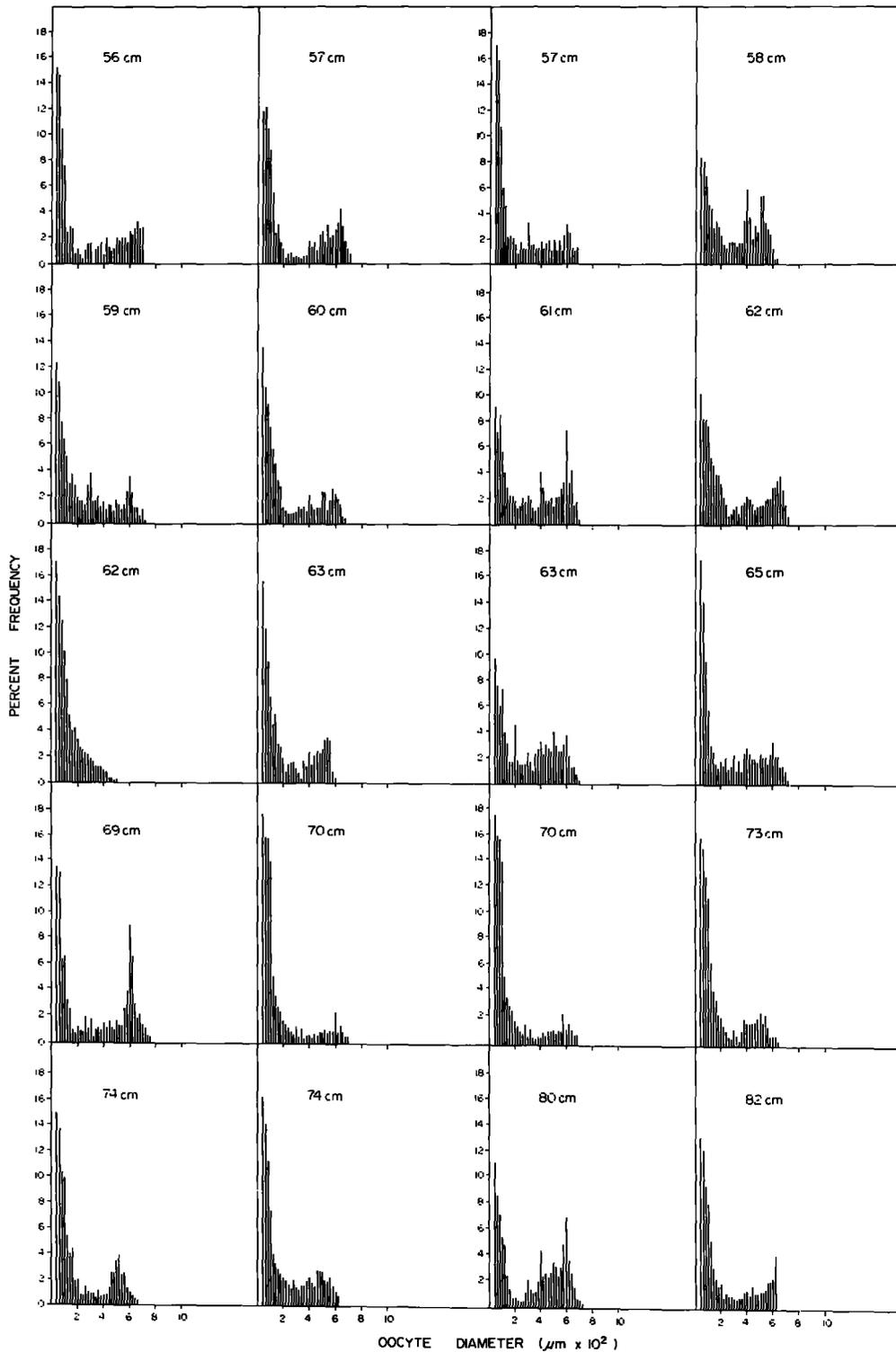


FIGURE 3.—Representative frequency distributions of oocyte diameter from ovaries of Pacific hake 56-82 cm FL.

TABLE 1.—Regression equations for oocytes of several size classes, and some combinations of same, found in prespawmed ovaries of Pacific hake from the Strait of Georgia, B.C.

Oocyte diameter (μm)	Oocyte description	Regression equation ($F = aFL^b$)	Correlation coefficient (r)
40-780	all oocytes	$F = 0.3081FL^{3.7605}$	0.93
40-180	unfolked reserve	$F = 0.0692FL^{3.9788}$	0.88
200-380	small, yolked	$F = 0.0446FL^{3.7097}$	0.86
400-580	medium, yolked	$F = 0.2078FL^{3.4174}$	0.71
600-780	large, yolked	$F = 0.0008FL^{4.8370}$	0.65
400-780	medium plus large yolked	$F = 0.1872FL^{3.5640}$	0.75
200-780	all yolked	$F = 0.5501FL^{3.3896}$	0.81

females in the number of maturing oocytes as their maturity stage advanced towards hydration. This may be both a reflection of the range in stage of maturity among individual females at a common time of collection, and variation among females in the proportion of yolked oocytes destined for hydration and release.

Apparent fecundity taken as the number of yolked oocytes $\geq 200 \mu\text{m}$ was best expressed by the equation $F_a = 0.5501FL^{3.3896}$. The averaged female hake in the Strait of Georgia stock (43.3 cm FL) contained an estimated 193,868 yolked oocytes $\geq 200 \mu\text{m}$ and had a relative apparent fecundity of 382.3 eggs/g. In comparison, an uncommonly large female (80 cm FL) could contain more than 1.5 million yolked oocytes for a specific fecundity of 477 oocytes/g (Table 2).

Pacific hake in the Strait of Georgia grow rapidly to age 4, showing almost linear growth in length (McFarlane et al. 1983). Thereafter, growth decreases rapidly and is accompanied by considerable individual variation in annual growth. The largest female in the sample (82 cm FL) was age 18 whereas another female age 15 was only 49 cm FL. Not surprisingly, age was weakly related to apparent fecundity and wide individual differences in ap-

TABLE 2.—Total and relative (oocytes/g body weight) fecundity estimates at fork length for unfolked (40-180 μm diameter) and yolked (200-780 μm diameter) oocytes found in prespawmed ovaries of Pacific hake from the Strait of Georgia, B.C.

Fork length (cm)	Unfolked oocytes		Yolked oocytes		% yolked of unfolked
	Total	Relative	Total	Relative	
40	162,502	406	148,178	370	91.1
45	259,580	455	220,887	388	85.3
50	394,666	507	315,679	403	79.5
55	576,544	551	436,089	417	75.7
60	814,896	598	585,684	430	71.9
65	1,120,308	645	788,233	443	68.7
70	1,504,260	693	987,611	455	65.7
75	1,979,132	739	1,247,812	466	63.1
80	2,558,196	786	1,552,943	477	60.7

parent fecundity are evident within age classes (Fig. 4).

Frequency Distributions of Oocyte Diameter in Postspawners

Gonads of 276 adult Pacific hake, trawl-caught on 3 July 1981, were staged superficially for maturity after Foucher and Beamish 1977. All gonads were in postreproductive state. The ovaries of 18 of 111 females retained for microscopic analysis were distributed within the various maturity states with these results: spent (1), recovering (7), and resting (10). Yolked oocytes (200-500 μm) were found in 7 ovaries: spent (1), recovering (4), and resting (2). Number of oocytes $\geq 200 \mu\text{m}$, expressed as a percentage of the oocytes $< 200 \mu\text{m}$ (40-180 μm) was $< 3\%$ in 6 of these fish, and 11% in the seventh, compared with 85-90% in prespawmed ovaries collected in March (Table 2).

These results support previous conclusions that not all yolked oocytes larger than 200 μm diameter are released, as suggested by Foucher and Beamish (1980) and MacGregor (1966). They also suggest that resorption in postspawmed females probably does not exceed about 5% of the yolked oocytes destined for release.

The female Pacific hake in the Strait of Georgia appears to use progressively less of the reserve fund of unfolked oocytes present during gonadal maturation in subsequent spawnings (Table 2), although relative and apparent fecundity increases with increased fork length. This can be illustrated by comparing females < 55 cm FL (Figs. 1, 2) with larger females (Fig. 3). The number of reserve fund oocytes in the size fraction 40-180 μm increases at a faster rate, almost doubling the relative fecundity for reserve fund oocytes in this size fraction by 80 cm FL than does production of larger oocytes. The reserve fund may have several origins, and cytological evidence was presented by Foucher and Beamish (1980) that the fund may be supplemented by cells of follicular origin in the postspawmed ovary. Such a mechanism to increase potential fecundity would appear to be rather redundant if significant resorption of yolked oocytes commonly occurs.

Stock Differences in Fecundity and Estimates of Spawning Stock

Methodological differences or lack of disclosure, and lack of substantiated assessment of stock-specific resorption following spawning, render it impossible to draw very useful comparisons of fecun-

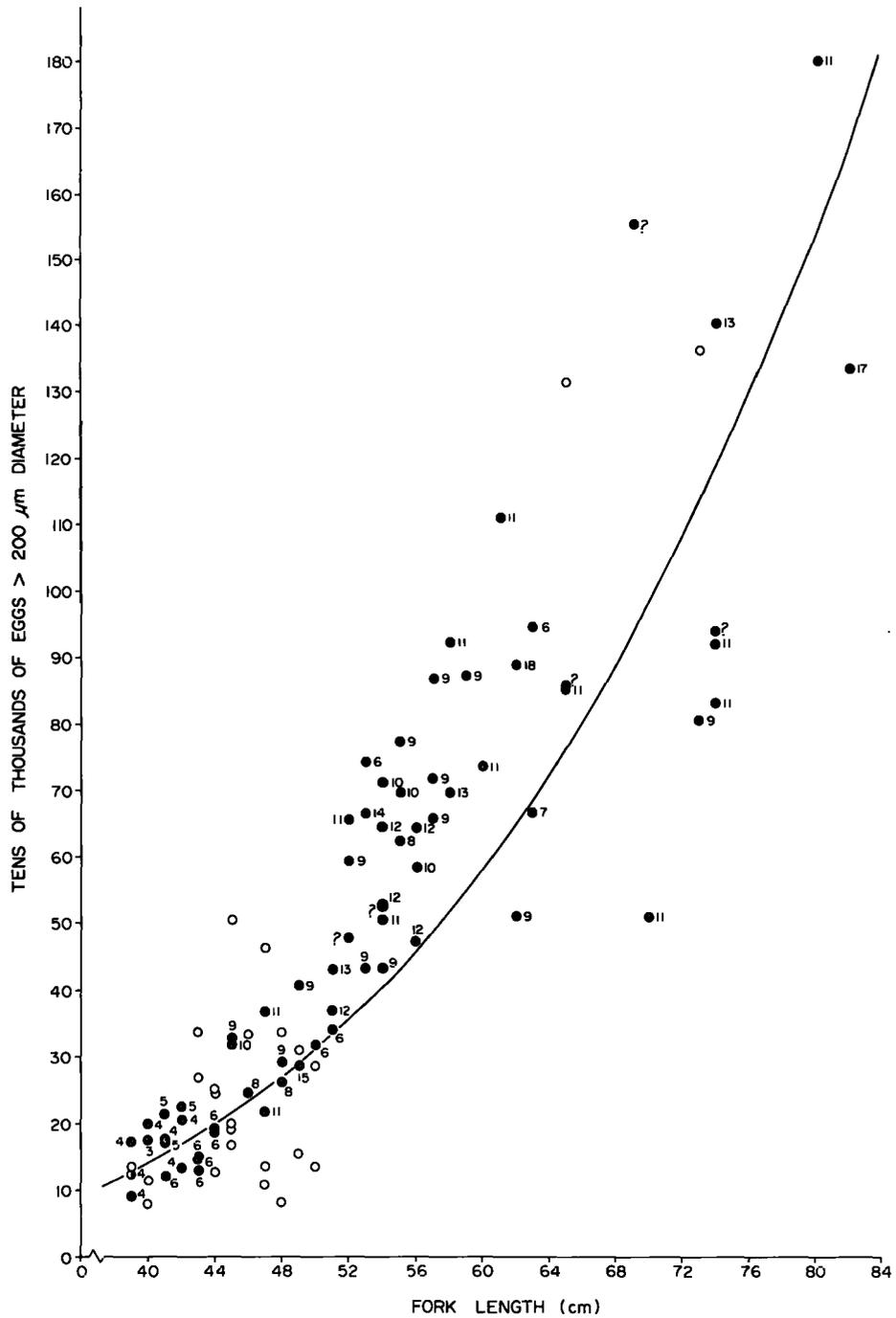


FIGURE 4.—Estimated number of yolked oocytes $\geq 200 \mu\text{m}$ diameter in 97 hake ovaries from the Strait of Georgia, B.C., plotted against fork length of female hake. Numbers adjacent to individual plots indicate estimated age of female; open circles - 1980 females, closed circles - 1981 females.

dity between coastal and inshore stocks of Pacific hake at this time. Ermakov et al. (1974) excluded oocytes <100 μm diameter, thus excluding a large fraction of unyolked oocytes constituting the reserve fund. Their estimates of total fecundity (comparable fork length) are one-half to one-third of those reported here for hake in the Strait of Georgia (≥ 40 mm) and are also lower than the present estimates for apparent fecundity (oocytes ≥ 200 μm diameter).

MacGregor (1966, 1971) counted advanced, yolked oocytes (>600 μm) only, premised on his assumption that only these cells were destined for release. On the basis of relative fecundity (eggs per gram), for yolked oocytes >580 μm diameter of comparable size to MacGregor's "large, yolked" or "advanced" oocytes, the female Pacific hake in the Strait of Georgia are considerably less fecund (54-164 eggs/g) over the fork length range of 40-80 cm than are Baja California hake which averaged 216 eggs/g (MacGregor 1971). However, the lack of distributional bimodality in the Canadian ovaries renders such a comparison unrealistic, for a common size threshold for resorption, even if appropriate, cannot be applied conveniently to individual ovaries.

We can state with reasonable certainty that resorption of yolked oocytes is a common occurrence in both coastal and inshore stocks of Pacific hake, as has been found in other forms of *Merluccius* (Hickling 1930; Christiansen 1971). The influence of ovarian resorption on annual fecundity of stock and on the magnitude of released egg production from individual females remains unknown. It follows that the application of existing fecundity information to problems of assessing magnitude of Pacific hake spawning stock from released egg production, as determined through ichthyoplankton surveys, should reflect these reservations.

For the Pacific hake stock in the Strait of Georgia, British Columbia, resorption may not involve more than 5-10% of the apparent fecundity. Hence, spawning biomass estimates based on released egg production and the apparent fecundity could be rendered conservative by the observed extent of resorption in this stock.

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STRANDED ANIMALS AS INDICATORS OF PREY UTILIZATION BY HARBOR SEALS, *PHOCA VITULINA CONCOLOR*, IN SOUTHERN NEW ENGLAND

Since Federal protection began in 1972, the New England population of harbor seals, *Phoca vitulina concolor*, has more than doubled (Gilbert and Stein 1981¹; Payne and Schneider 1984), increasing at a site in southeastern Massachusetts at an average rate of 11.9% per year (Payne and Schneider 1984). One of the primary management concerns regarding the New England seal population is the increasing potential for conflict between commercial fisheries and harbor seals (Prescott et al. 1980²).

Seals have been shown to be significant consumers

¹Gilbert, J. R., and J. L. Stein. 1981. Harbor seal populations and marine mammal fisheries interactions. National Marine Fisheries Service, NOAA, Northeast Fisheries Center, Contract No. NA-80-FA-C-00029, Woods Hole, MA 02345, 55 p.

²Prescott, J. H., S. D. Kraus, and J. R. Gilbert. 1980. East Coast/Gulf Coast Cetacean and Pinniped Workshop. Marine Mammal Commission (MMC), Final Report, Contract 79/02. (Available National Technical Information Service, Springfield, VA 22151 as PB80-160104, 142 p.)

of marine production (Brodie and Pasche 1982) and have been implicated as competitors for commercially valuable fish stocks, impacting fisheries through direct predation, gear damage, and entanglement (Boulva and McLaren 1979; Everitt and Beach 1982; Brown and Mate 1983). Despite the significant increase in harbor seal abundance, only anecdotal information exists on the diet of harbor seals along the eastern United States. To assess the impact of this common predator on fish and squid, information is required on the food species exploited.

In the past, seals were killed to facilitate quantitative analysis of their stomach contents (Imler and Sarber 1947; Spalding 1964; Boulva and McLaren 1979; Pitcher 1980a), although this procedure is impractical in New England. Two alternatives to this method are the analysis of the stomachs of stranded animals, and the examination of seal feces collected on accessible haul-out sites (Pitcher 1980b; Treacy and Crawford 1981; Brown and Mate 1983).

The first alternative for determining the food habits of the southern New England seal population was provided by the more than 500 harbor seals that have been found stranded south of Maine since 1977. The stranded seals were collected by the New England Aquarium (NEA), Boston, MA. The majority (59%) of the seals were collected between January and March (Table 1) along the perimeter of Cape Cod Bay, MA, primarily on the eastern side. This corresponds to the time when the peak number of seals occur south of Maine (Schneider and Payne 1983). Most of the stranded seals (65%) came from one year, 1980 (Table 1), when over 445 seals died of acute pneumonia associated with influenza virus (Geraci et al. 1982).

Upon necropsy at the NEA, most of the stomachs and intestinal tracts of the stranded seals were found to be empty. Only 63 stomachs contained food matter, and the contents from those were frozen for later

TABLE 1.—Monthly distribution of stranded *P. v. concolor* containing prey items examined 1977-83.

Month	1977	1978	1979	1980	1981	1982	1983	Total
Jan.	1			15			1	17
Feb.				7	2		1	10
Mar.				10				10
Apr.				1				1
May				1	1	2	1	6
June		1				2	1	4
July						1		1
Aug.				2		1	1	4
Sept.				3		2		5
Oct.				1				1
Nov.				1				1
Dec.						1		3
Totals	1	1	3	41	3	9	5	63